Search for a Higgs Boson Decaying to Two *W* Bosons

Jennifer Pursley, on behalf of the authors

University of Wisconsin-Madison

CDF Weekly Meeting – Paper Seminar

Sept. 18, 2008

PRL Draft: CDF Note 9368

Paper Details

- Supporting Documentation
  - Full list on godparent webpage:

http://www-cdf.fnal.gov/internal/physics/godparents/HWW_2fb/

  - Main analysis note:
    - For 2.4 fb^{-1}, CDF 9195
    - For update to 3.0 fb^{-1}, CDF 9402
  - Public note, CDF 9236
  - PRL Draft, CDF 9368
  - Also: 9163, 8977, 8958, 8923, 8774, 8719, 8700, 8647, 8538, 8128
- Thanks to godparents
  - Rainer Wallny (chair), Craig Group, Oliver Stelzer Chilton
- ... and all who read the drafts, especially:
  - Fermilab, Pisa, OSU, UC-Davis, SPRG

Authors

The HWW group ⇒

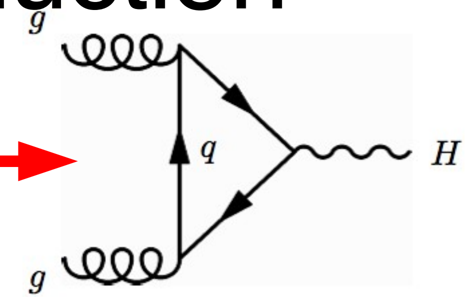
Godparents	Rainer Wallny (chair) Craig Group (literary) Oliver Stelzer Chilton
Conveners	Matthew Herndon Mark Kruse
Physics Coord	Doug Glenzinski
Spokes	Rob Roser Jaco Konigsberg

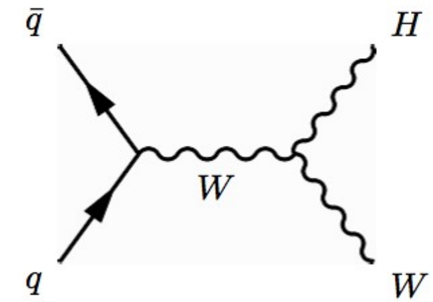
22 People from 8 institutions!

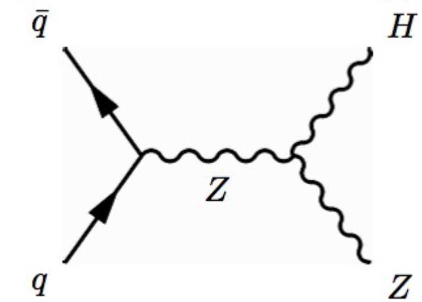
Duke University	
Dean Andrew Hidas	Valentin Necula
Doug Benjamin	Mark C. Kruse
FNAL	
Susan Burke	Sergo Jindariani
Eric James	
IEP Slovakia	
Roman Lysak	
INFN Padova	
Maria D'Errico	Simone Pagan Griso
Donatella Lucchesi	
UCSD	
Shih-Chieh Hsu	Elliot Lipeles
Frank Wurthwein	
University of Glasgow	
Toby Davies	Aidan Robson
Stan Thompson	Richard St. Denis
Peter Bussey	
UIUC	
Mark Neubauer	
Wisconsin	
Jennifer Pursley	Matthew Herndon

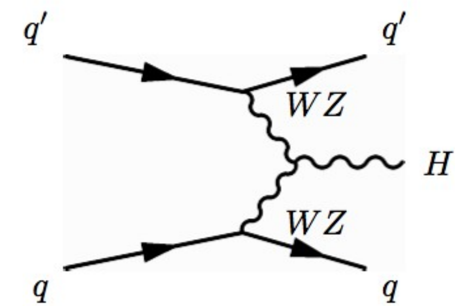
Standard Model Higgs Production

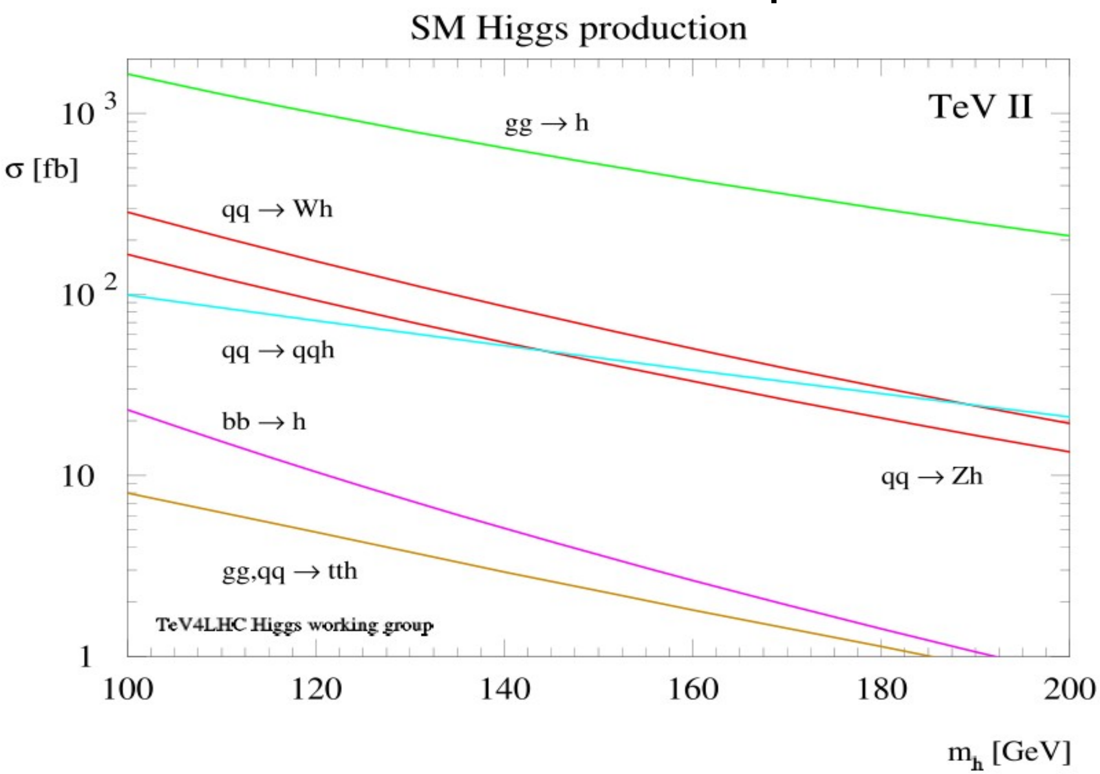
- Four main production mechanisms
  - Gluon fusion dominant process at Tevatron
    - Only process considered in this analysis
  - Associated production (ZH, WH) and vector boson fusion contribute to production + jets





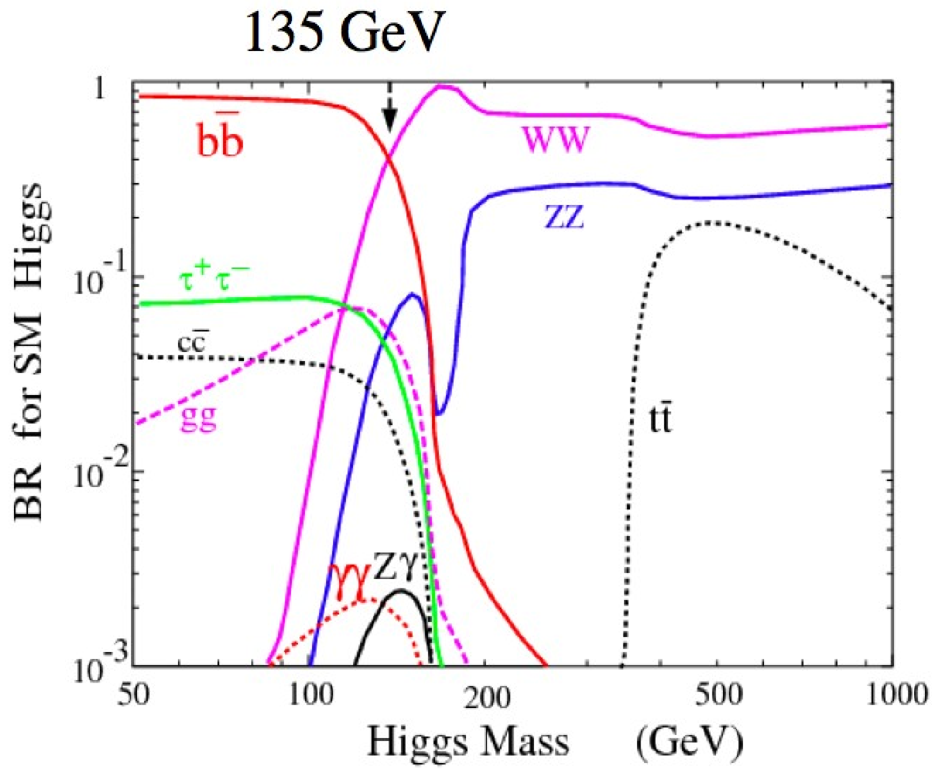


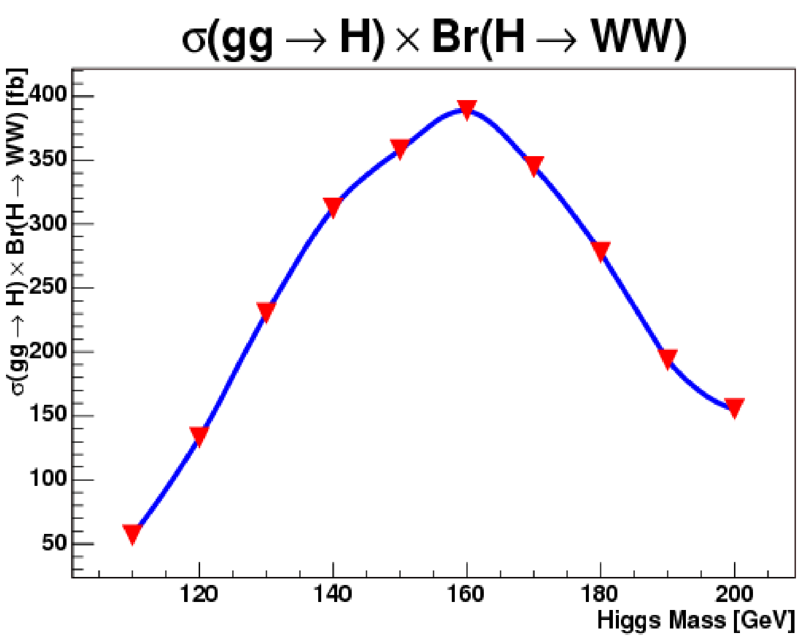




Standard Model Higgs Decay

- Higgs decay modes depend on Higgs mass M_H:
  - $M_H < 135$, predominantly to $b\underline{b}$
  - $M_H > 135$, predominantly to W^+W^-





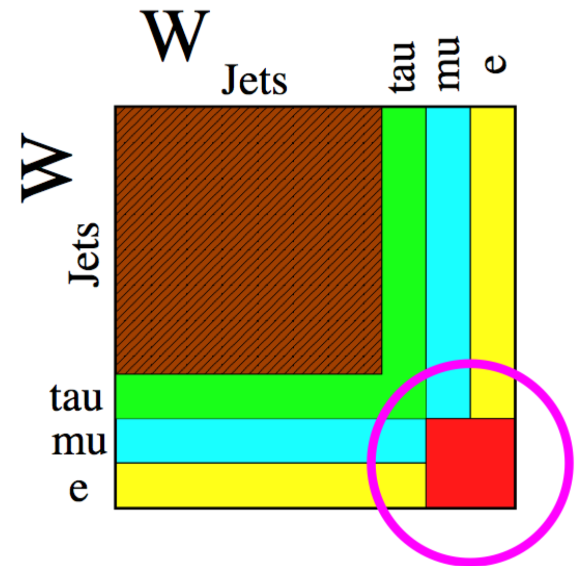
- For gg → H → WW σ x BR,
  - Peak sensitivity at $M_H \sim 160$
  - Comparable sensitivity to VH→Vb$\underline{b}$ at $M_H \sim 130$

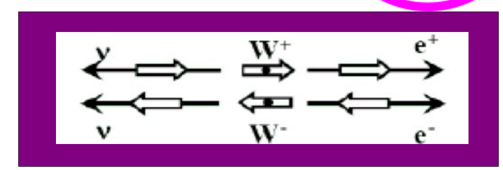
Analysis History

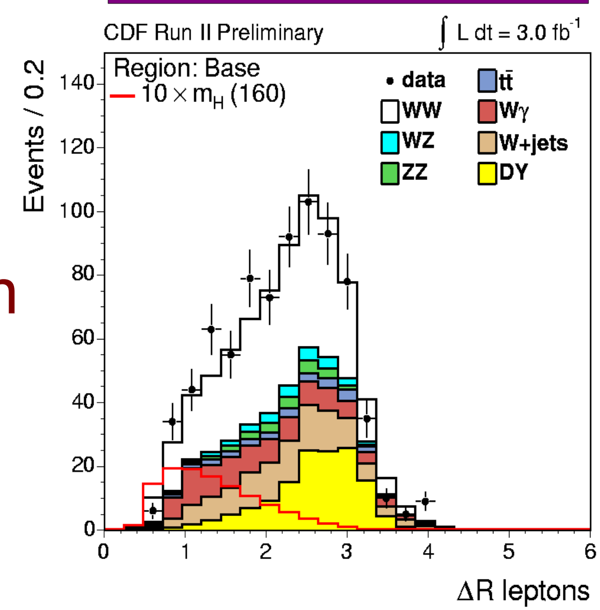
- PRL on CDF $H \rightarrow WW$ result in May 2006 with 360 pb^{-1}
  - Used dilepton opening angle ($\Delta\phi_{ll}$) to discriminate signal from background
  - Expected limit at 160 is 8.5 x σ_{SM}
- Preliminary result: CDF Note 8774 March 2007
  - Extended lepton selection, matrix element method on 1.1 fb^{-1}
  - Expected limit at 160 is 4.8 x σ_{SM}
- Preliminary result: CDF Note 8700 March 2007
  - Neural network method on 1.0 fb^{-1}
  - Expected limit at 160 is 4.7 x σ_{SM}
- Preliminary result: CDF Note 8958 August 2007
  - Matrix element method on 1.9 fb^{-1}
  - Expected limit at 160 is 3.1 x σ_{SM}
- Preliminary result: CDF Note 9236 February 2008
  - Matrix element + neural network on 2.4 fb^{-1}
  - Expected limit at 160 is 2.5 x σ_{SM}
  - For publication: Updated dataset to 3.0 fb^{-1} $\rightarrow$ 2.2 x σ_{SM} at 160

H → WW Signature

- W decay modes:
  - Leptonic 33% (e, μ, τ), Hadronic 67%
- Dilepton (e, μ): BR ~ 6%
  - Sensitive to τ → (e, μ)
  - Small BR, but clean, easy to trigger
- H → WW → $\ell\nu\ell\nu$ signature:
  - 2 high p_T leptons (e or μ)
  - Missing transverse enegy ($\not{E}_T$)
  - WW pair from spin-0 Higgs boson:
    - Leptons tend to point same direction
- $\ell\ell$ opening angle strongest discriminant
- Use multivariate techniques (ME, NN)

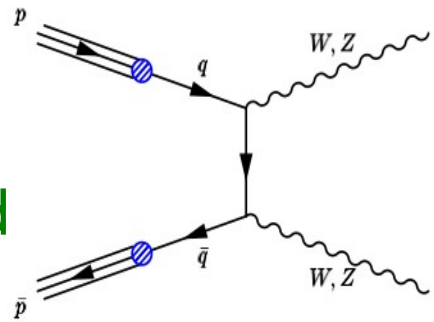




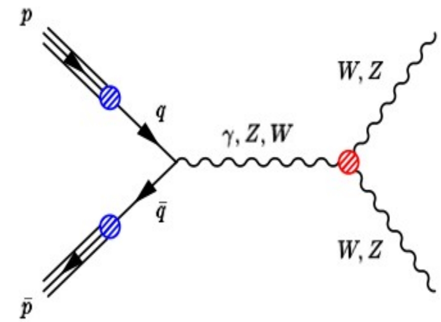


Standard Model Backgrounds

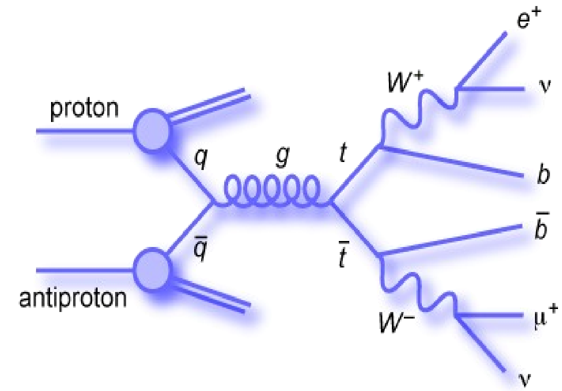
- SM processes create a variety of backgrounds:
  - WW – Largest background
  - Heavy diboson: WZ, ZZ
  - $t\bar{t}$ and single top
  - Drell-Yan ($Z \rightarrow \ell\ell$)
  - W + jets/γ
- All cross sections measured by CDF
  - Discovery analyses: WW, WZ, ZZ, single top
- Must understand backgrounds to set a limit

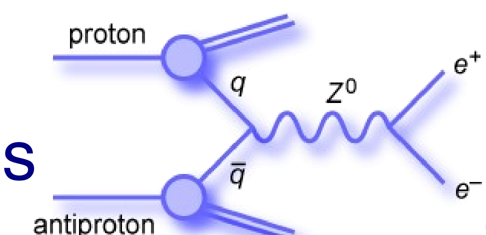


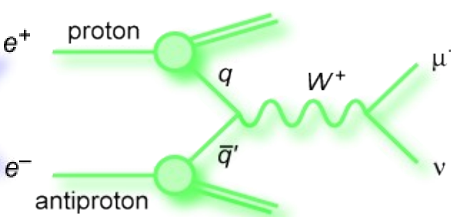
t-channel



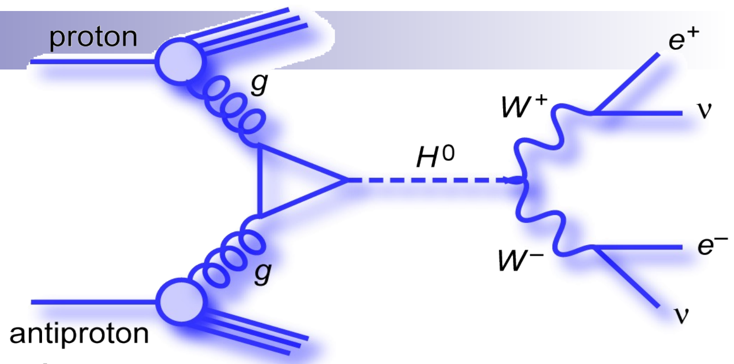
s-channel







Event Selection



- Select dilepton events in 3 fb^{-1}
  - Two opposite charge leptons (e or μ)
    - Extended lepton selection:
      - TCE, PHX, CMUP, CMX, CMIOCES, CMIOPES, CrkTrk
      - Divide into high S/B and low S/B lepton categories
    - $p_T(\ell_1) > 20$, $p_T(\ell_2) > 10$ GeV/c
  - Dilepton mass $M_{\ell\ell} > 16$ GeV/c^2
  - Special $\not{E}_T$ cuts suppress DY with mismeasured leptons/jets:

$\not{E}_{T\ \mathrm{spec}} > 25\ (ee, \mu\mu)$ or $\not{E}_{T\ \mathrm{spec}} > 15\ (e\mu)$, where

$$\not{E}_{T\ \mathrm{spec}} \equiv \begin{cases} \not{E}_T & \text{if } \Delta\phi(\not{E}_T, \text{lepton}, \text{jet}) > \frac{\pi}{2} \\ \not{E}_T \sin(\Delta\phi(\not{E}_T, \text{lepton}, \text{jet})) & \text{if } \Delta\phi(\not{E}_T, \text{lepton}, \text{jet}) < \frac{\pi}{2} \end{cases}$$

  - Require less than 2 jets with $|\eta| < 2.5$ and $E_T > 15$ GeV

Event Selection, continued

- Use the following standard triggers
  - CENTRAL_ELECTRON_18, MUON_CMUP_18, MUON_CMX_18, MET_PEM
  - One lepton required to confirm trigger
  - Apply appropriate pre-scaling
  - Require candidates to be in appropriate good run list
- Background modeling:
  - WW modeled by MC@NLO
  - All other bkgs modeled by Pythia or Baur ($W\gamma$), except...
  - W+jets uses data-driven estimate of fake leptons
    - Select identified leptons (numerator) and “fakeable objects” (denominator) in jet data samples
- Calculate lepton ID efficiencies and scale factors using Z candidates in high p_T e and μ data and MC

Expected Sample Composition

- Use control regions to check background modeling
  - Drell-Yan region: test lepton SF, triggers, lumi accounting
  - Same sign region: test fake lepton contributions
  - Low $\not{E}_T$ significance or low $\not{E}_{T\ spec}$: test effects of mismeasured energy
  - All regions show good data-MC agreement
- Expected gg → H → WW signal:

TABLE I: Expected Higgs boson yield as a function of m_H

m_H (GeV/c^2)	110	120	130	140	150	160	170	180	190	200
Expected Yield	0.5	1.9	4.3	7.0	9.3	11.6	11.0	9.0	6.4	5.1

- Expected background events:
  - Background prediction agrees with observed events

$\int \mathcal{L} = 3.0\ \mathrm{fb}^{-1}$

WW	356	±	49
WZ	24.9	±	3.9
ZZ	21.8	±	3.5
$t\bar{t}$	25.5	±	5.0
DY	138	±	31
$W\gamma$	90.5	±	24.1
W+jets	111	±	27
Total background	**768**	±	**91**
Data		**779**	

HWW 0 or 1 Jets

Matrix Elements

$$P(\vec{x}_{obs}) = \frac{1}{\langle\sigma\rangle} \int \frac{d\sigma_{th}(\vec{y})}{d\vec{y}} \, \varepsilon(\vec{y}) \, G(\vec{x}_{obs}, \vec{y}) \, d\vec{y}$$

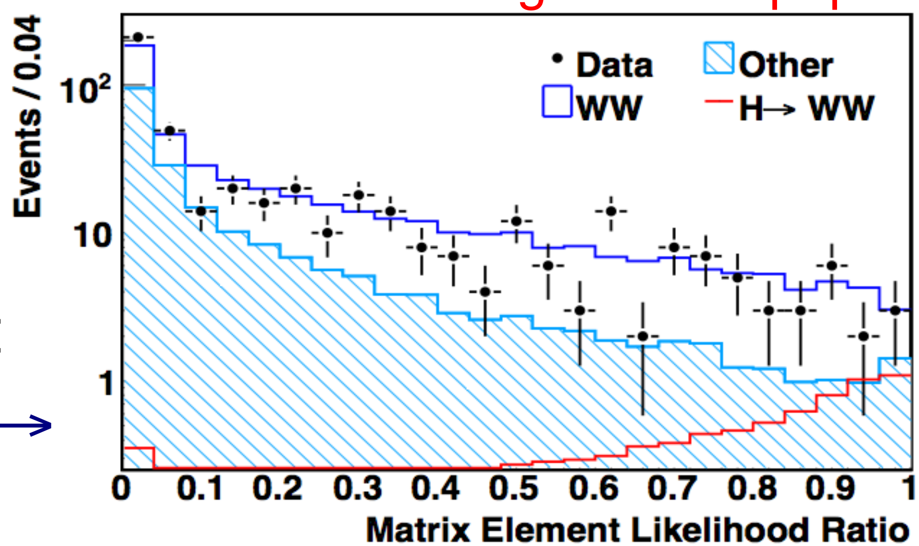
$$LR_m = \frac{P_m(\vec{x}_{obs})}{P_m(\vec{x}_{obs}) + \sum_i k_i P_i(\vec{x}_{obs})}$$

- Event probability density, with:

$\vec{x}_{obs}$	Observed leptons and $\not{E}_T$
$\vec{y}$	True lepton 4-vectors (l, ν)
σ_{th}	Leading order theoretical cross-section
$\varepsilon(\vec{y})$	Efficiency & acceptance
$G(\vec{x}_{obs}, \vec{y})$	Resolution effects
$1/\langle\sigma\rangle$	Normalization

- Calculate 5 probabilities:
  - HWW, WW, ZZ, Wγ, W+jet
- Construct Likelihood Ratio → (for M_H = 160, high S/B)

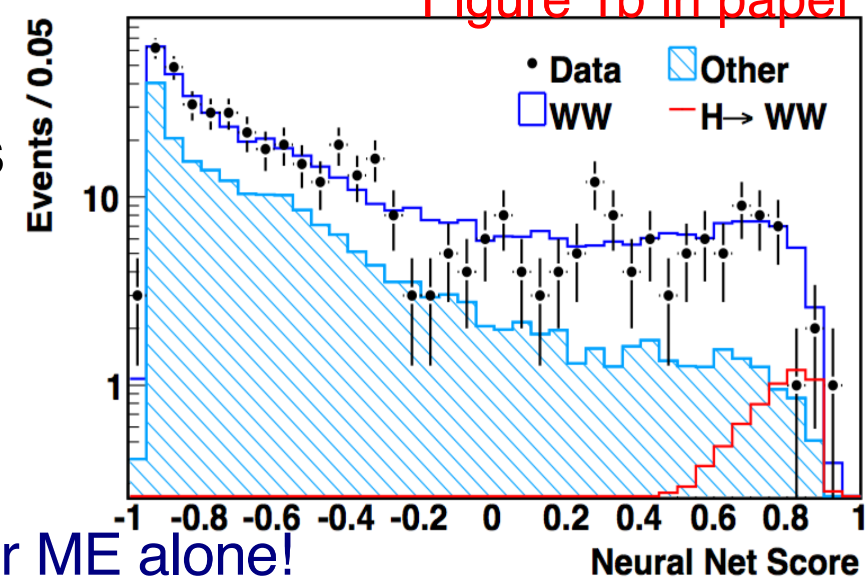
Figure 1a in paper



Matrix Element + Neural Network

- Use LR and kinematic variables as inputs to neural net:
  - All 5 LR + $\Delta\phi_{ll}$, ΔR_{ll}, m_{ll}, $\not{E}_T$, $\Delta\phi_{ET,(l,jet)}$, $\not{E}_{T\ spec}$
  - Most important variables are LR_{HWW}, ΔR_{ll}, $\not{E}_{T\ spec}$
- NeuroBayes NN (cross-checked with TMVA)
  - Input layer with 11 nodes, hidden layer with 12 nodes, output layer with 1 node
  - Trained on weighted sample of signal + background events
    - Signal given score of +1, background score of -1
  - One NN for each Higgs mass
  - NN template for M_H = 160 →

Figure 1b in paper



- ~10% improvement in sensitivity over ME alone!

Systematics

- Largest uncertainties from theoretical cross-sections
  - Compare WW Pythia MC to MC@NLO to estimate higher order (NLO acceptance) effects
  - PDF uncertainties assessed using 20 CTEQ PDFs
  - W+jets: uncertainty on jet being identified as a lepton
    - Different for high and low S/B lepton categories

	Fractional Uncertainty (%)							
	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jets	Higgs
$\not\!\!E_{\mathrm{T}}$ Modeling	1.0	1.0	1.0	1.0	20.0	1.0	-	1.0
Conversions	-	-	-	-	-	20.0	-	-
NLO Acceptance	6.2	10.0	10.0	10.0	5.0	10.0	-	10.0
Cross-section	10.0	10.0	10.0	15.0	5.0	10.0	-	10.0
PDF Uncertainty	1.9	2.7	2.7	2.1	4.1	2.2	-	2.2
LepId $\pm 1\sigma$	1.5	1.4	1.4	1.4	1.4	1.2	-	1.4
Trigger Eff	2.2	2.3	2.2	2.1	3.5	7.1	-	3.5
WW Scale	1.7	-	-	-	-	-	-	-
DY SF Scale	2.7	2.7	2.7	2.7	2.7	2.7	-	2.7
Total	12.7	14.9	14.9	18.5	22.1	25.8	28.8/23.4	15.1

Limit on Higgs Production

- Use MCLimit program from Tom Junk
- Show both ME only and ME+NN limits in paper:

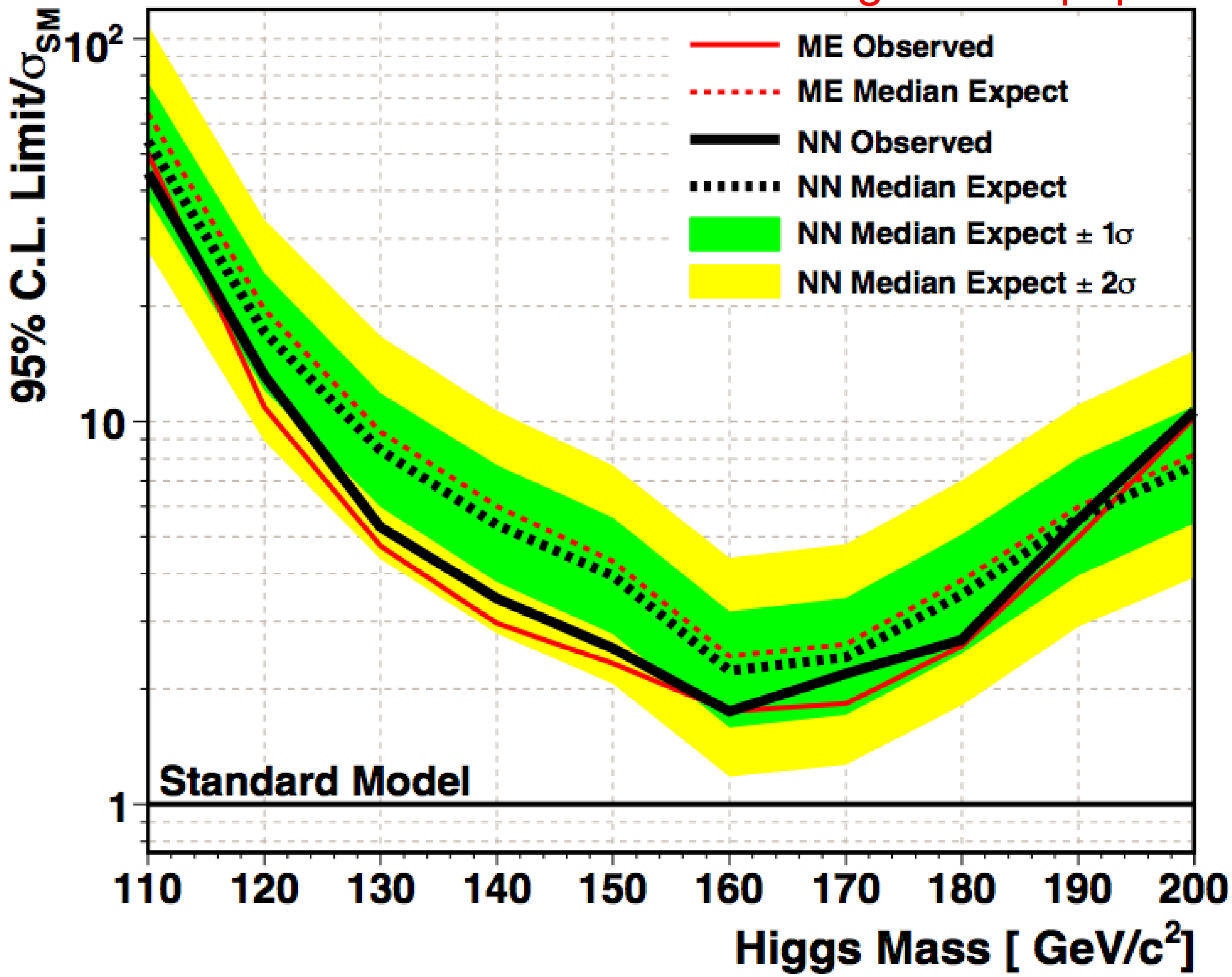
TABLE II: Expected and observed limits on $\sigma(gg \to H) \times \mathcal{B}(H \to WW^{(*)})$ and $\sigma(gg \to H) \times \mathcal{B}(H \to WW^{(*)}) / \sigma_{\mathrm{SM}}(gg \to H) \times \mathcal{B}_{SM}(H \to WW^{(*)})$ as a function of m_H.

m_H (GeV/c^2)	110	120	130	140	150	160	170	180	190	200
Using Matrix Element Only										
Expected (pb)	3.6	2.6	2.2	1.9	1.5	0.9	0.9	1.1	1.2	1.3
Observed (pb)	2.8	1.5	1.1	0.9	0.8	0.7	0.6	0.7	1.0	1.5
Expected/SM	63.7	19.6	9.4	6.0	4.3	2.4	2.6	3.8	6.0	8.2
Observed/SM	50.3	10.9	4.7	3.0	2.3	1.7	1.8	2.6	5.0	10.3
Using Neural Net Discriminator										
Expected (pb)	3.0	2.3	1.9	1.7	1.4	0.9	0.8	1.0	1.1	1.2
Observed (pb)	2.5	1.7	1.2	1.1	0.9	0.7	0.7	0.7	1.0	1.6
Expected/SM	54.0	17.1	8.4	5.4	3.9	2.2	2.4	3.5	5.6	7.7
Observed/SM	44.6	13.2	5.3	3.5	2.6	1.7	2.2	2.7	5.5	10.6

$H \rightarrow WW$ Limits in 3 fb^{-1}

Figure 2 in paper

Observed limit at M_H = 160:
0.7 pb or
1.7 x σ_{SM}



Summary

- First update to CDF limit on $H \rightarrow WW$ since 360 pb^{-1}
  - Expected limit moves from 8.5 to 2.2 x σ_{SM}
  - Many improvements in between, including
    - Extended lepton acceptance and selection
    - Background modeling
- First use of multivariate techniques in $H \rightarrow WW$ search
  - Both ME and NN described in paper
- Significant contribution to Tevatron Higgs combination
  - Leading up to a CDF-only exclusion
- Ready for submission to PRL
  - Thanks again to godparents and reading institutions for helpful comments!